Spatial and temporal heterogeneity of the comprehensive fertility of soils under oil palm after EFB application

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Context: The empty fruit bunches (EFB), a mill by-product resulting from the extraction of palm oil, can be recycled in the palm plantations in partial substitution of mineral manures. How to manage organic residues and mineral fertilizers regarding the comprehensive fertility (physical, chemical and biological) of soil? Our research project addressed the impact of these organic inputs on soil biota and associated physical and chemical parameters. The goal is to use the comprehensive soil fertility as a tool in ecological intensification. The current study relates the characterization of both spatial and temporal heterogeneity within the plots.

Study site: Trial sites: Libo Estate, Riau/Sumatra – Indonesia

Figure 1: Six sampling times after EFB application

Spatial study

Materials and Methods

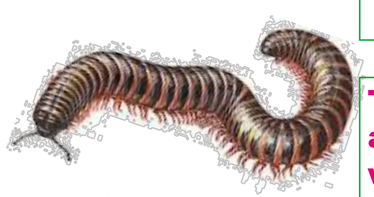
Five zones around the palm were determined based on the heterogeneity of the habitat around the tree, and the spatial heterogeneity of chemical and organic fertilizers applications (Figure 2).

Two practices were studied:

- "EFB"(60 t/ha every two years)
- "Conv" without EFB as control.

Soil samples were taken three months after EFB application on P zone. Samples were analysed for:

- Chemical & physical parameters,
- Macrofauna,
- Nematofauna,
- Microorganisms.



Results

A formula was developed to calculate the mean value of the plot:

Plot mean = $\sum(S_i \times D_i)$; where S_i = (area of zone i) / (total area of plot), and D_i = data of zone i (where i = P, PC, C, CW, W).

For the EFB practice, chemical richness was more important on P and C zones than on W zone. Also, the macrofauna was more abundant on PC and C zones than on W zone (**Table 1**).

When comparing both practices ("Conv." and "EFB"), the EFB application was correlated with significant increase of chemical and biological parameters on P and PC. The impact extended significantly to C and W zones for some characteristics (Table 1).

On the PCA, earthworms showed a different pattern than other macrofauna taxa **(Figure 3a).** In Conv., $PC_{/Conv.}$ and $P_{/Conv.}$ had similar characteristics, but different from $C_{/Conv.}$ and $CW_{/Conv.}$ that are also different from $W_{/Conv.}$. While in EFB plots, $PC_{/EFB}$ showed a different pattern than all other zones, not different between them **(Figure 3b)**.

Nematofauna density was low in most studied areas (3 ind.g^{-1} of soil), except for the C zone in Conv (8 ind.g^{-1} of soil). Microorganism DNA density was lower in EFB plot than in Conv, particularly for C and W zones.

Based on these results, we can suggest to consider three zones in Conv. (P+PC, C +CW, and W) and four zones when EFB is applied along the pathway (P, PC, C+CW, and W) for further studies.

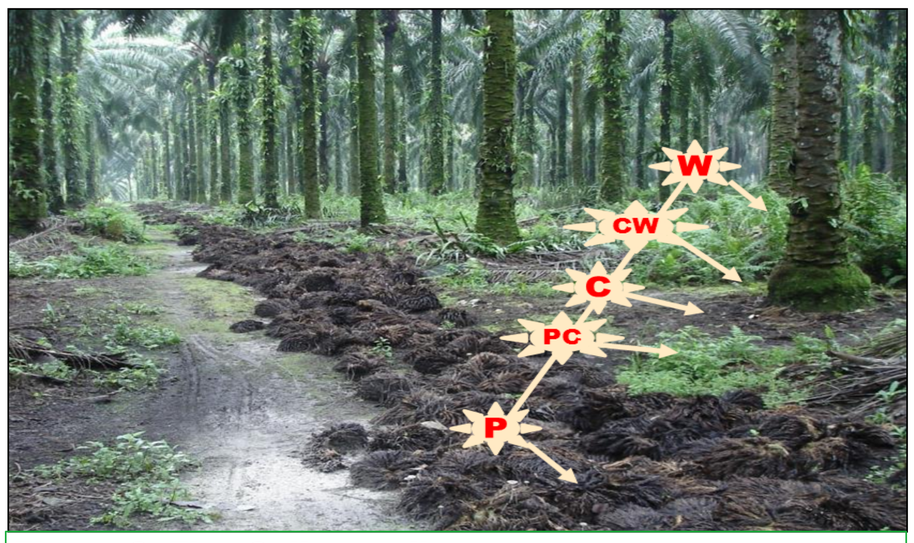


Figure 2: Five Soil sampling zones: P: Pathway, PC: transition zone between P and C, C: Circle, CW: transition zone between C and W, W: Windrow.

Table 1: Comparison of the evolution of chemical and biological characteristics around a palm with or without EFB application

+ higher value, - lower value, compared to W/EFB used as reference
The soil parameter was improved , decreased , compared to the same zone in Conv

Conv					Soil parameters	EFB				
P	PC	C	CW	W		P	PC	C	CW	W
					pH	+++				←
	++	+++			P	+		++		←
		+			K	+++	+	++		←
-	-	+			CEC	-		+		←
-	-	+		-	Ca			+	-	←
		+			Mg	+	+	++		←
		+	+		Saturation	+++	++	++		←
---	---	-	-		Organic cover (biomass)		--	-	-	←
--			-	-	Macrofauna (biomass)	-	+	+		←
--	-	-	-		Macrofauna (Density)	-	-		-	←
--	-	++	-	-	Earthworms (Density)	--	++	-	-	←
---	-	-	-		Ants (Density)	--	---		-	←
---	---			-	Dermaptera (Density)	---	---			←

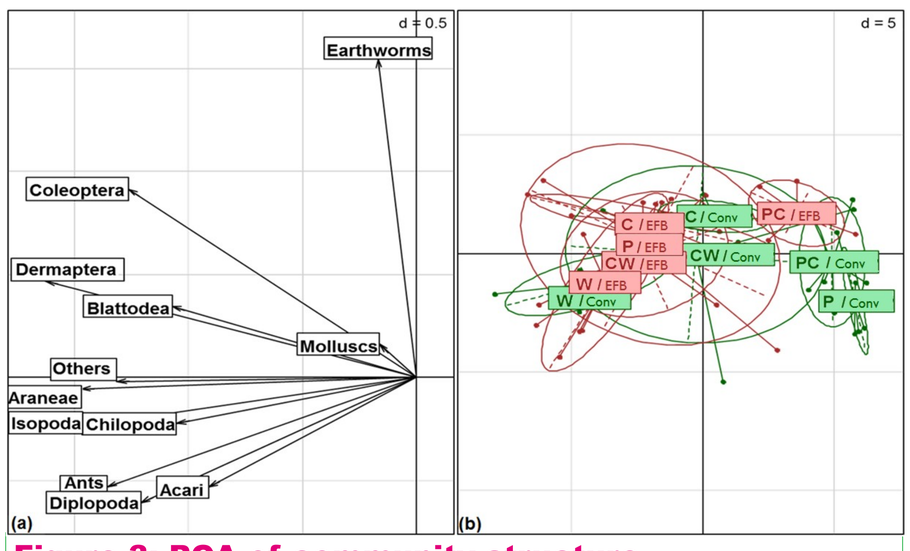
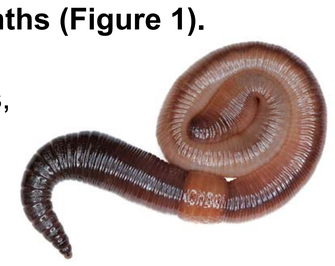


Figure 3: PCA of community structure
(a) Variables: soil macrofauna taxa. (b) Ordination of sampling zones in the plane defined by the first two axes. Labels correspond to the barycentres of zone/treatment. (Monte Carlo test, p < 0.01, Observation = 0.42)

Temporal Study

Materials and Methods

- The temporal heterogeneity of the soil characteristics under EFB applied on harvest pathway (P zone) was assessed on plots receiving EFB every two years. The control was P zone in Conv without EFB application.
- A time-sequence with six points was built, taking into account the length of time after the application of EFB; i.e. after: **1, 3, 6, 12, 18, and 24 months (Figure 1).**
- Soil samples were analysed for:
  - Chemical & physical parameters,
  - Macrofauna,
  - Nematofauna.



Results

The evolution of chemical and biological parameters led to identify three periods:

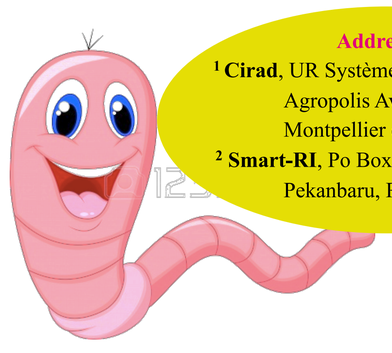
- The **first period** (first 6 months following the EFB application) was characterised by a **strong disturbance** of all soil parameters. Particularly, it resulted in a significant increase in pH, K, base saturation and macrofauna abundance, mostly the ants. In the same time, we observed a strong reduction of the earthworm and nematode populations.
- The **intermediate period** (between 12th and 18th month after EFB application) looked like a **resilience** time.
- The **last period** (starting from the 24th month) **was marked by the maximum improvement** of most of the fertility parameters: bulk density, CEC, N, Ca, C and clay. It was also characterized by a maximum abundance in earthworms, earwigs (Dermaptera), and millipedes (Diplopods).
- The nematofauna was more abundant over the two last periods and more balanced on the functional level, testifying the effectiveness of the resilience.

Table 2: Changes in organic soil layer (0 to 3.5 cm) on P zone for the three periods after EFB application, compared to P zone in Conv

Soil parameters	1 to 6 months	12 to 18 months	24 months
Bulk density	+	++	+++
C organic	+	+	++
pH	+++	+	
N tot	+	+	++
K	+++	+	+
CEC	++	+	+++
Ca	+	++	++
Saturation	+++	++	+
Organic cover (biomass)	+++	++	+
Macrofauna density	+++	+	++
• Earthworms	-	++	+++
• Ants	+++	+	+
• Coleoptera	+++		++
• Diplopodes	- - -	+	+++
• Dermaptera	+	+	+++
Nematofauna density		++	++
• N bacterivorous		+	++
• Maturity Index (MI)	-		
• Index for breaking down (NCR)	+		

Conclusion & Perspectives

- Sampling and analysis methods, adapted to this type of cropping system having complex spatio-temporal heterogeneity, are proposed
- Our results show that EFB can improve the comprehensive soil fertility and reduce spatial heterogeneity in the plot. Particularly, the application of EFB induce strong disturbance of soil characteristics during first 6 months; but then, all characteristics gradually improve, except K. After 24 months. fertility of $P/_{EFB}$ is still significantly higher than $P/_{Conv}$.
- Our work provide first methods and data towards a holistic approach of the soil fertility under mature oil palm.
- They bring new highlight on the impacts of organic application in space and time. They raise new questions on how to manage inorganic and organic fertilization practices (types, doses and frequencies) regarding the comprehensive soil fertility.



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